SMT Reflow: Facing the Challenges

Mass reflow may be well documented in terms of operational theories, but theory alone does not solve reflow problems.

Darius Samsami, Associate Editor

This article examines some common reflow problems and various attempts to bring them under control. Problems typically encountered in printed circuit assembly operations today include temperature gradients across the board, loading conditions and changeover time, liquidus dwell and varying environmental conditions.

Temperature gradients

It is important for boards to be heated uniformly to prevent thermal shock, solder wicking and defects associated with extended dwell at liquidus temperatures. However, temperature gradients do tend to arise from board corners to the center area and also depend on the distribution of thermal mass across the board.

Mike Glynn, marketing/sales manager for ETS, says that many systems are simply not capable of maintaining low temperature gradients, left to right, especially on high mix boards. To assist in heating boards with larger thermal mass along board edges, some lamp IR ovens incorporate rail mounted edge heaters. Depending on the substrate material, adjusting belt speed to allow absorption and conduction of energy can also assist in minimizing thermal gradients.

Sometimes categorized as IR/natural convection ovens, panel IR systems generally heat air more readily than lamp emitter systems. Convection becomes a significant heat transfer mechanism, in addition to radiation, because of the natural flow created by the heated air.

Phil Zarrow of Vitronics Corp. says that by controlling the convection aspect of panel IR systems to an even greater degree, an IR/controlled convection oven is able to minimize temperature gradients across the board. This also compensates for the tem-

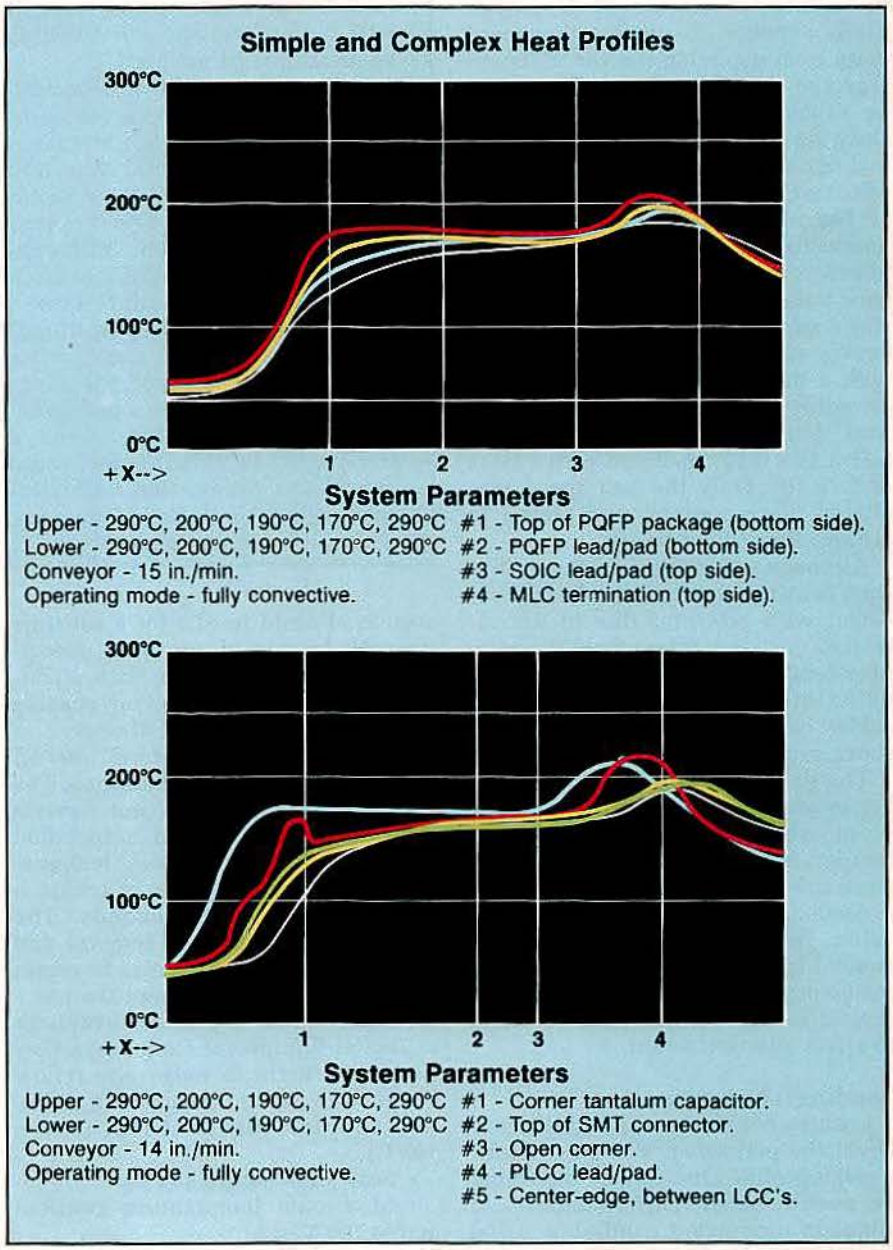

***Figure 1. Simple and complex assemblies** can be run through a forced convection oven at identical set points, but at different conveyor speeds to yield acceptable profiles. (Conceptronic, USA)*

Lamp IR systems use radiation as the primary heat transfer mechanism

perature differential that may exist across the surface of the panel, especially under loaded conditions when boards in the center of the conveyor pull heat from the center of the panel.

Fully forced or controlled convection ovens closely approach an equilibrium heating situation. That is, the temperature of the boards is brought to the temperature of the heating medium — the heated gas. According to Michael Roffey of Watkins-Johnson, the control of temperature gradients in convection systems depends upon the volume of gas moved. If enough gas is supplied to prevent the board mass from depleting the gas of its energy, the temperature of the board can be raised in a controlled manner. Once up and running, differing thermal masses can usually be heated by adjusting conveyor speed.

Figure 1 shows profiles for two different assemblies run through a full forced convection oven with identical zone temperatures. The first assembly was a simple, low component density, double-sided 4 x 6 x 0.62 in. board with a mass of 0.14 lbs. The second assembly was a complex, high component density, 12 layer, single-sided 9.75 x 14 x 0.125 in. board with a mass of 1.39 lbs. Only the belt speed was altered (decreased by 1 in./min.) to achieve the second profile.

Although vapor phase is an equilibrium heating process, it has been associated with problems due to uncontrolled heating rates. Bob Paavola, president of Centech, says that the addition of IR preheat has eliminated solder balling, wicking and thermal shock problems.

The preheat also brings the assembly to within 40-70°C of the eutectic point while maintaining allowable temperature gradients. From there, since the vapor temperature cannot be exceeded, large gradients cannot develop. In fact, time differences between high and low mass areas reaching eutectic does not generally exceed several seconds, which does not seem to affect joint formation.

Loading/changeover

Loading conditions can significantly affect the performance of an oven for a given profile. One way to determine an oven's loaded performance is to simulate production conditions using a load test.

Each vendor has its own spec, but most share a common structure; the oven is allowed to idle for a set time interval, boards of specified dimensions are fed to the oven with a constant board center-to-center spacing for a set time interval, the oven is again idled for the set time interval and is loaded for the second time. The resulting profiles must not deviate from each other beyond a specified amount. Additionally, peak temperature times must coincide to within a specified number of seconds. The longer the loading time interval and the shorter the board center-to-center distance, the more stringent the test.

Kathy Frame, a product evaluator at Digital Equipment Corp., says they use five criteria to judge any reflow system:
- Ramp up and ramp down.
- Liquidus dwell time (above 183°C).
- Soak time (above 153°C).
- Maximum temperature gradient across the board.
- Chamber heating uniformity.

Digital Equipment Corp. uses a thin laminate, mixed density board to obtain both a static profile and a profile under loaded conditions. Frame says that although their loading test spec does not call for zero board spacing, they usually run a profile under these conditions also. Experience has shown that performance of the oven in this worst case scenario is indicative of the oven's performance.

For captive manufacturing operations, product changeover time may not be a relevant concern. Production schedules may dictate changeovers occur only once a day or even less frequently. However, for large volume contract manufacturers, changeovers may occur three or four times a day and down time is critical.

Lamp IR systems use radiation as the primary heat transfer mechanism, exhibit a high power-to-mass ratio, and are thus very responsive. However, they are vulnerable to varying thermal loads which require compensation by overcoming greater temperature differentials. Some manufacturers have developed greater control

Rocky Road to Reflow

Many challenges to the mass reflow process have already been addressed by advances in process and equipment technology. For instance, high internal component temperatures are less frequent today with reflow systems that are well controlled. Even full convection ovens, which operate at higher temperatures than other IR ovens, do not heat the die as much as fluorinated vapor, which is still well below package post molding temperatures (about 300°C).

Process changes have been suggested to decrease occurrences of moisture-induced delamination and cracking of ceramic chips and high-lead-count plastic packages. Ricardo Perez of Compaq Computer Corp. in Houston, Texas presented a paper at SMTA's Surface Mount '90 which details how a controlled storage environment and determination of a maximum moisture level content specification can eliminate these problems.

Double-sided reflow, once a challenge, is routine for some operations today. Some double-sided reflow is done in one pass, but this generally requires added adhesive dispensing, curing and board flipping steps for components on the bottom side. More common is two-pass, double-sided reflow.

Equipment manufacturers had to maintain a wide top to bottom temperature differential to prevent bottom side solder from becoming liquidus and to prevent the components from falling off.

Some operations opted to use a high or low temperature solder and flux material on one side and a standard material on the other and then perform the second reflow operation with a different peak temperature. However, high temperature reflow causes charring to some substrate materials. Also, low temperature joints look dull and can be incompatible with some reliability tests.

Requirements for a wide temperature differential could be lessened by placing heavier components on the top side and relying on solder surface tension to hold onto bottom side components. Mike Glynn of ETS points to one

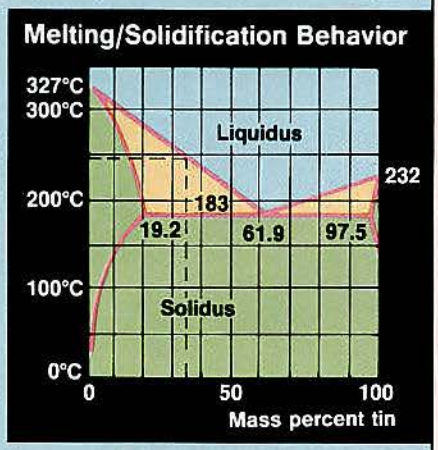

Figure A. Tin-lead phase diagram showing the eutectic temperature of 183°C and the eutectic composition of about 62 percent of tin.

test performed on a 32-mil thick multilayer board with several 120-pin gull wing devices on the bottom side. With a temperature differential of 10-15°C top to bottom, there was no problem with component fall-off. Conceptronic's Stephen Dow notes that even though bottom side solder may reach eutectic point, it may not become completely liquidus (Fig. A)[1].

of air flow to help decrease the vulnerability of these ovens to thermal loads, with a slight trade-off in response time.

Panel IR systems are much less influenced by varying thermal loads because the panels are so massive. Therefore, in spite of panels having a slow response due to lower power-to-mass ratios, they have a smaller temperature differential to overcome. Improved panel control capability has decreased panel IR systems' susceptibility to temperature overshoot problems, a former complaint of some users. At least one panel IR system employs ambient air movers at the oven chamber's entrance and exit to assist the exhaust, greatly improving response time when changing profiles.

Thermal capacity can be determined in vapor phase systems. If this is not exceeded, loading has little effect on performance. To changeover to a new profile, the belt speed is adjusted. IR preheat temperatures are rarely altered, so changeover times are not usually a problem.

Although controlling temperature gradients is important, it is not the only goal. As mentioned earlier, dwell time at the liquidus temperature is critical. Too long of a dwell time will increase the formation of intermetallic compounds and affect the reliability of the solder joints. Conversely, too short of a dwell time will also be detrimental to solder joint formation. Recently there has been a move to reduce dwell times.

Vitronic's Zarrow says that a higher proportion of IR, in comparison to convective energy at the reflow spike, followed by accelerated quenching/cooling, allows a reduction in liquidus dwell in panel IR ovens. At press time, Reliance Electric in Athens, Ga., in association with Vitronics, is conducting a study to quantify the relationship between liquidus dwell and solder joint reliability characteristics.

Paavola of Centech notes that the advent of single-vapor systems has decreased the size of the vapor zone, thus decreasing liquidus dwell. The addition of forced air cooling zones also contributes to shorter liquidus dwell in vapor phase systems.

Environmental conditions

As more domestic manufacturers consider setting up operations overseas, factory environments or climates become a concern. Does air quality, mainly humidity, affect the soldering process? The answer, according to Kris Hill of Universal Instruments, is yes. The exception to this comes in the case of vapor phase systems where water vapor is expelled during the initial vaporization process and cannot re-enter the chamber while the vaporization temperature of the inert material is maintained.

However, Stephen Dow, reflow systems product manager for Conceptronic, asserts that although extreme humidity may alter reflow profiles, it will first affect solder materials and the printing process. Recommendations, such as maintaining 40-60 percent relative humidity, abound but hard specifications do not. This is because the effects of humidity are dependent on the material chemistry.

CFC elimination

As electronics manufacturing moves toward the elimination of CFCs, the reflow process may also be affected. Dave Heller, of Heller Industries, Florham Park, N.J., predicts that the use of no-clean solder pastes will become the standard for the surface mount industry sometime during the 1990s. The use of nitrogen atmospheres to assist the fluxing action of these no-clean pastes for fine-pitch applications will also increase. There are reflow manufacturers who already have experience with controlled atmospheres and these firms may have an initial advantage when incorporating this into their reflow machines.

However, many other alternatives to CFCs have been proposed. Until large PCB manufacturers and the military finish their evaluation of these options and make their requirements known, there will be a need for guesswork among the solder material and equipment manufacturers.

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References

1. R. J. Klein Wassink, *Soldering in Electronics,* Electrochemical Publications Ltd., Ayr, Scotland, UK; 1989; p. 142.

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